PB88-236 229

Cadmium Emissions from Primary Lead and Primary Copper Smelting: Phase 1 Technical Report

(U.S.) Environmental Protection Agency
Research Triangle Park, NC

Jun 88

U.S. Department of Commerce
National Technical Information Service
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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-450/3-88-006		PB88-236229/AS

4. TITLE AND SUBTITLE	5. REPORT DATE
Cadmium Emissions From Primary Lead and Primary Copper Smelting - Phase I Technical Report	June 1988
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Office of Air Quality Planning and Standards U.S. Environmental Protection Agency Research Triangle Park, N.C. 27711	10. PROGRAM ELEMENT NO.
	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS DAA for Air Quality Planning and Standards Office of Air and Radiation U.S. Environmental Protection Agency Research Triangle Park, North Carolina 27711	13. TYPE OF REPORT AND PERIOD COVERED
	14. SPONSORING AGENCY CODE EPA/200/04

15. SUPPLEMENTARY NOTES

16. ABSTRACT

A technical report on cadmium emissions from primary lead and primary copper smelting. Descriptions of these industries and associated air pollution control equipment are presented. Cadmium emission estimates for all U.S. plants in these two source categories and health risks from exposure to these emissions from each plant are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Pollution Control Cadmium Emissions Primary Lead Refining Primary Copper Refining	Air Pollution Control	13B

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Unlimited	Unclassified	38
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

United States
Environmental Protection
Agency

Office of Air Quality
Planning and Standards
Research Triangle Park NC 27711

EPA-450/3-89-028

PB88-236229

EPA

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Emission Standards Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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TECHNICAL REPORT:
PRIMARY LEAD AND COPPER SMELTING

I. DEFINITION OF SOURCE CATEGORIES

Cadmium, as an impurity in many nonferrous ore concentrates, is emitted during the smelting process. This report describes the sources of cadmium emissions from primary lead and primary copper smelters, documents the health risks attributable to these emission sources, and discusses the potential for improvements in existing levels of control.

A. Primary Lead Smelters

1. Plants in operation. There are currently five primary lead smelters located in three States. The following three plants are currently operating: the ASARCO smelter in East Helena, Montana; the ASARCO smelter in Glover, Missouri; and the St. Joe smelter in Herculaneum, Missouri. The lead smelter in Boss, Missouri, previously owned by a partnership of AMAX and Homestake Lead Tollers, was acquired in full by Homestake in June 1986. This smelter, referred to as AMAX-Boss for this study, was immediately closed after Homestake's acquisition. The ASARCO smelter in El Paso, Texas, has been closed since 1985. Both ASARCO and Homestake have stated that no reopening date has been scheduled, and a decision to reopen these smelters will be based on market conditions.[1,2]

2. Processes. Figure 1 shows the lead smelting process. Processes include sintering, reduction, and refining. Ore concentrates, that typically contain 20 to 70 percent lead and 13 to 19 percent sulfur, are blended with return sinter, flue dusts, and fluxes and are fed to a sintering machine.[3] Sintering results in the oxidation of lead and sulfur present in the charge to lead oxide (PbO) and sulfur dioxide (SO_2). Simultaneously, the charge material is converted to a dense permeable material called sinter. The sinter is crushed, mixed with metallurgical coke, and charged to a blast furnace where carbon monoxide formed by burning coke reduces PbO to elemental lead. In addition, impurities with an affinity for oxygen, such as iron, react with the fluxes and are

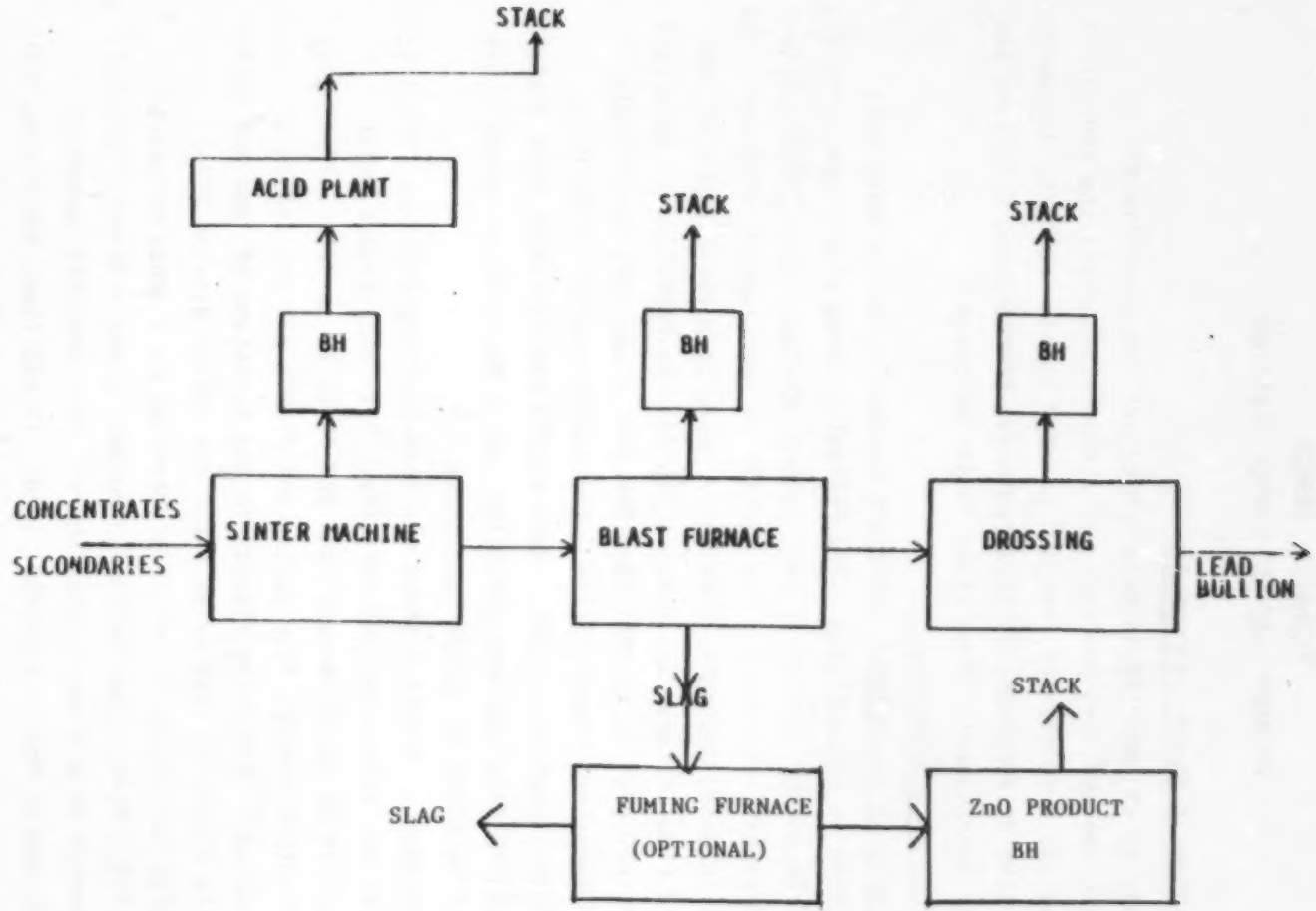

Figure 1. The lead smelting process.

collected in a molten slag. Both the slag and lead bullion are tapped continuously from the furnace. The waste slag is either disposed of directly, or, as is the case at two smelters, it may be charged to a zinc fuming furnace where the zinc in the slag is vaporized to zinc oxide. The residual slag is then discarded.

The crude lead bullion is transferred to a series of refining kettles where impurities are selectively removed as drosses. Typically, the drosses are treated in a reverberatory furnace where additional lead is recovered and metals, such as copper and arsenic, are concentrated. The dross is skimmed and recycled while the product lead bullion is pumped from the drossing kettles into molds.

3. Projections of industry growth. Federal regulations on lead in gasoline, in existence since 1976, have reduced the demand for lead. Depressed lead prices and foreign competition have resulted in the temporary closure of two of the five domestic smelters. No growth in lead demand is projected through the year 2000 and no new smelters are expected to be built.[3]

B. Primary Copper Smelters

1. Plants in operation. There are currently 14 primary copper smelters located in 7 States. Nine smelters are operating and five are closed. Of the nine smelters which remain open, two are scheduled to close permanently in 1987. The five smelters which are closed now could reopen if market conditions improve.

2. Processes. Figure 2 shows the copper smelting process. The winning of copper from ore concentrates involves the following processes: (a) roasting the ore concentrates (optional), (b) smelting the roasted calcine or unroasted ore concentrates and fluxes to form an intermediate copper-bearing product called matte, and (c) converting (oxidizing) the matte to produce blister copper (approximately 99 percent pure copper). Six of the 14 smelters roast ore concentrates prior to smelting. In this step, ore concentrates, which typically contain 15 to 30 percent copper, are charged to the roaster. The concentrates are heated, but not melted, in the presence of oxygen so that much of the sulfur in the concentrate is oxidized to SO_2. Volatile impurities such as arsenic also are emitted during this process.

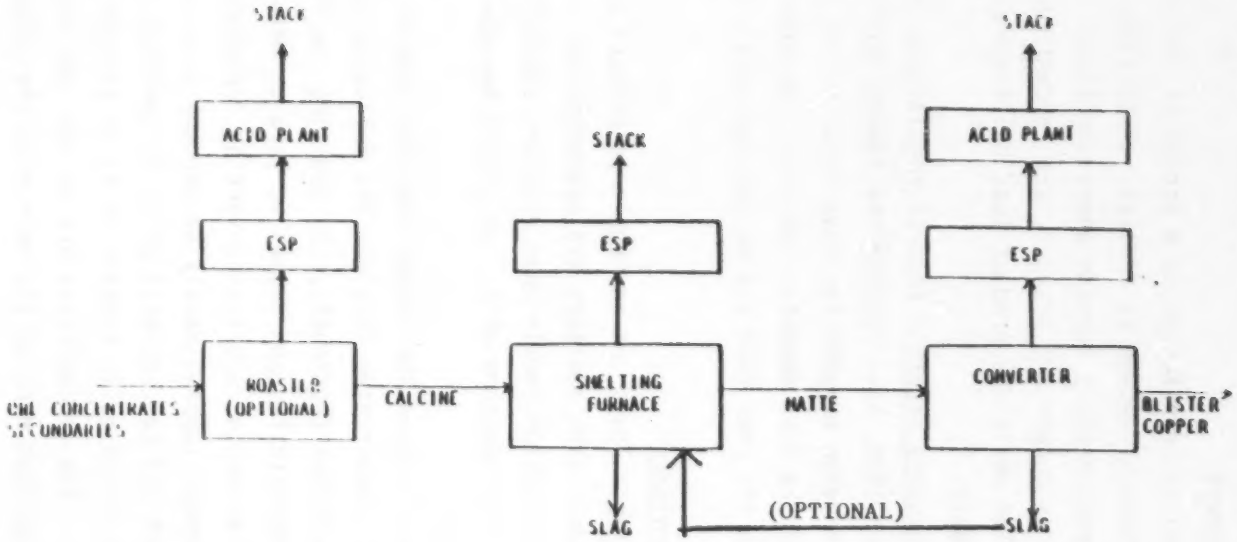

Figure 2. The copper smelting process.

The roaster product (calcine), or, if the roasting process is not used, ore concentrates mixed with flux, are then charged to a smelting furnace. Here, copper and iron combine with sulfur to form the molten matte. Lighter impurities, such as zinc and oxides of iron, silicon, and calcium, float to the top of the furnace and are drawn off as slag which is then either recycled to the smelting furnace or discarded. The copper-rich matte, a mixture of copper sulfides and iron sulfides, is tapped from the bottom of the furnace and is transferred to the converters by ladle. In the converter, fluxes are added and air is blown through the matte. First, the iron sulfide is oxidized to various iron oxides which are skimmed off as slag and discarded or recycled. This slag skimming operation leaves impure copper sulfides. Next, the copper sulfides are oxidized to copper and SO_2. The converter operation is terminated at this point to prevent further oxidation of the copper to copper oxide. The SO_2 laden off-gases are ducted to control devices for particulate removal and then are either used to produce byproduct sulfuric acid (at 11 smelters) or emitted directly to the atmosphere (at 3 smelters). Typically, the product blister copper is further refined in an anode furnace prior to casting of copper anodes for electrolytic refining. A more detailed discussion on the copper smelting process is contained in Reference 4.

3. Projections of industry growth. Demand for primary copper is expected to grow at 1.7 percent annually through the year 2000.[5] A world surplus of mine, smelter, and refinery capacity is expected to exist through 1990 leading to a permanent shift in smelter and refinery capacity away from the U.S.[5] No additional copper smelters are anticipated to begin operating in the near future. Two of the currently operating smelters are scheduled for permanent shutdown in 1987, and only 9 of the 14 smelters are currently operating.

II. EMISSIONS AND CONTROLS

A. Primary Lead Smelters

As an impurity in lead ore concentrates, cadmium is emitted in varying amounts at each stage of the smelting process. The typical lead ore concentrate contains 0.02 percent cadmium. The distribution of cadmium through the lead smelting process is shown in Figure 3. Approximately half

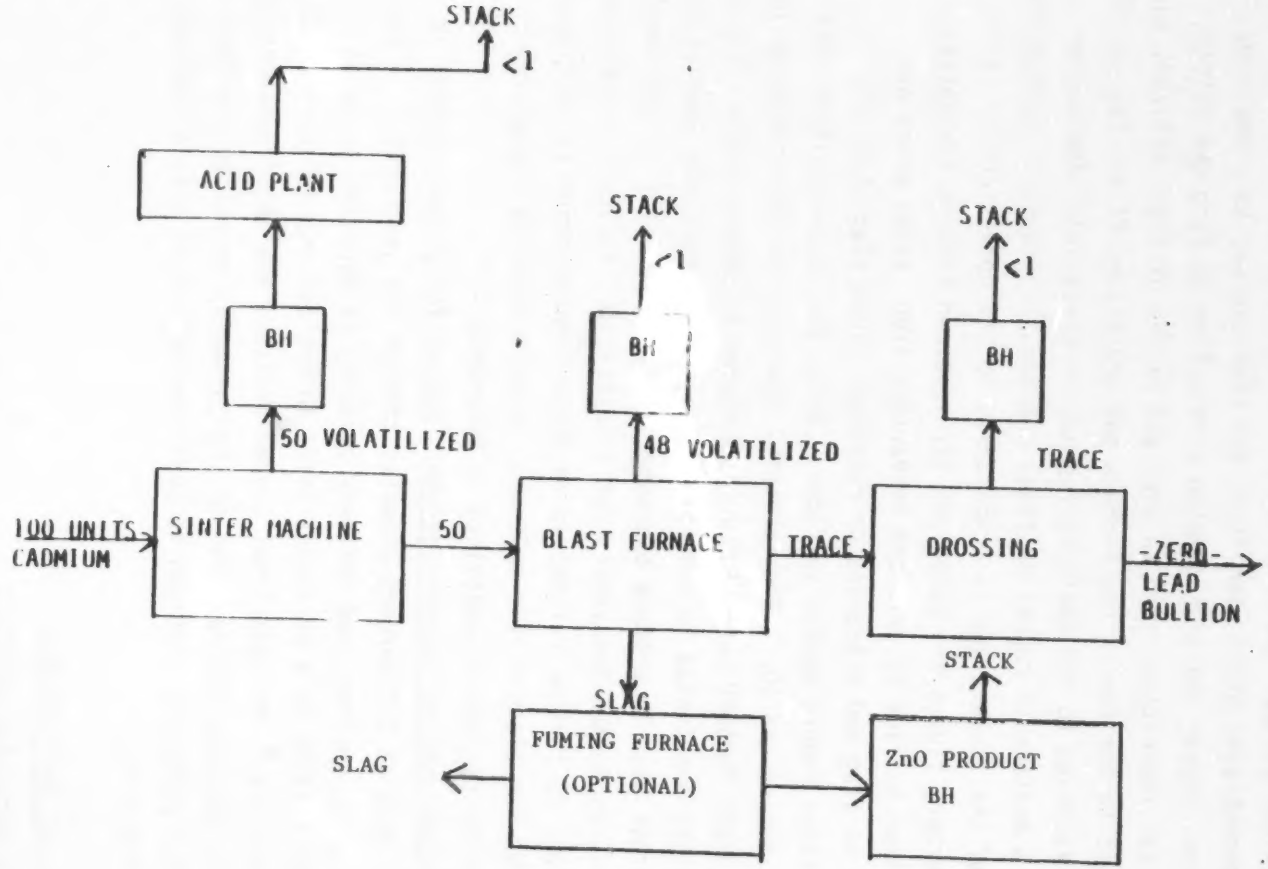

Figure 3. Cadmium distribution in the lead smelting process.

of the cadmium input to the smelter is volatilized in the sintering step and half is volatilized in the blast furnace with small amounts remaining in the slag. Other point sources of cadmium emissions at primary lead smelters include dross furnaces, slag fuming furnaces, and, at one plant, a cadmium oxide roaster. These sources are discussed in more detail below.

At three of the five smelters, the sinter machine produces two off-gas streams. One stream is taken from the charging end where the majority of the sulfur combustion takes place. This stream has a high SO_2 content (typically 4 to 7 percent) and is referred to as the strong off-gas stream.6 The second off-gas stream, taken from the discharge end of the machine, has a low SO_2 content (typically 0.5 percent) and is referred to as the weak off-gas stream.[6] The SO_2 in the strong off-gas stream can be recovered economically in a byproduct sulfuric acid plant. The gas is passed through a series of particulate control devices prior to acid conversion. A baghouse and/or an ESP is first used to reduce the particulate matter concentration. Particulate loadings are reduced further by wet treatment devices--scrubbers and spray towers. This extensive pretreatment is required to keep the particulate matter from poisoning the acid catalyst conversion beds. Thus, virtually no particulate matter or cadmium emissions are discharged from the acid plant stack. Sinter machine weak stream off-gases contain too little SO_2 to be converted to sulfuric acid economically. Therefore, they are emitted to the atmosphere after baghouse control.

The sinter machine at the ASARCO smelter in El Paso recirculates the weak stream off-gases with the strong off-gases to produce a single off-gas stream (from the charging end of the sinter machine) that contains approximately 6 percent SO_2. This stream is processed through an acid plant. The ASARCO-Glover smelter has no SO_2 control. Consequently, there is no concern to maintain a strong stream for an economical acid conversion. Thus, the sinter machine off-gas is a single stream containing gas from the entire length of the sinter machine. It is vented through a baghouse for particulate control, then to the atmosphere.

Process gases from blast furnaces at all five smelters are vented to a baghouse for particulate matter removal and discharged directly to the

atmosphere through stacks. The SO_2 concentration in the blast furnace off-gas is too low to be recovered economically in an acid plant.

At four of the five smelters, the blast furnace baghouse dust is recycled to the sinter machine. At the ASARCO smelter in El Paso, Texas, however, the blast furnace dust, which can contain up to 18 percent cadmium, is roasted in a Godfrey roaster to produce a crude cadmium oxide byproduct (66 percent cadmium). Cadmium oxide product from the roaster is collected in a baghouse which is vented through a louvered cupola.

Two smelters have slag fuming furnaces for zinc recovery: ASARCO-East Helena, and ASARCO-El Paso. Neither has operated the furnace since 1982. A decision to restart the furnaces will be based on the zinc market. Because of the possibility that these facilities may be restarted, they were included in the source assessment. However, since slag contains very small quantities of cadmium, the slag fuming furnace is a relatively minor source of cadmium emissions.

Process fugitive emissions result from leakage in and around process equipment and from the handling and transferring of materials. Control techniques include measures to preclude their occurrence and measures to confine and capture emissions. Once captured, emissions may be vented directly to a particulate control device or combined with process gases prior to control.

Major process fugitive sources include the handling and transfer of sinter machine and blast furnace flue dusts, sinter machine leakage, sinter crushing and handling, blast furnace charging, blast furnace upsets, and hot metal tapping and transfer operations. Process fugitive emissions from sinter charging and product handling and transfer operations can be limited by the use of dust suppressants (e.g., water sprays) and the application of local hooding and ventilation followed by a control device. Local hooding and ventilation techniques are also applied to the control of tapping emissions from blast furnaces and dross reverberatory furnaces, and the control of drossing kettles. Captured emissions are generally combined with the blast furnace process gases and treated in the blast furnace baghouse. Process fugitive emissions from sinter machine and furnace leakage can be minimized or eliminated by proper operation and maintenance. Control of process fugitives from flue dust handling includes enclosing

dust transfer points and conveyors and/or application of dust suppressants. Many of these controls have been put in place to comply with State implementation plans (SIP's) for fugitive lead emissions.

The Texas Air Control Board (TACB) has required the ASARCO smelter in El Paso to enclose all transfer and handling of dusts containing greater than 1 percent lead. If ASARCO decides to reopen the lead plant it must comply with this mandate.[7,8] The enclosures put in place to control lead emissions also will significantly reduce cadmium emissions.

The Montana lead SIP has required the ASARCO smelter in East Helena to install a number of control measures that have reduced lead and cadmium emissions. These include improved ventilation and covers for the dross kettles, an air pressure control system to reduce blast furnace upsets, and a blast furnace secondary hooding system vented to a baghouse. Montana estimates the particulate matter capture efficiency to be 95 percent for the blast furnace and 50 percent of the drossing operations.[9,10]

Open fugitive sources include ore concentrate storage piles, slag storage piles, and plant roadways and yard areas. In the case of ore concentrates and slag, the cadmium content is low (approximately 0.02 percent for ore and 0.005 percent for slag). As a result, potential cadmium emissions from these sources are relatively minor. Similarly, emissions from plant roadways and yard areas are also minor, due to both low cadmium content and measures taken to mitigate lead emissions. Control for open fugitives consists of wet suppression or enclosing the storage piles.

An inventory of cadmium emission sources at primary lead smelters and the existing controls is presented in Table 1. In general, the SIP's for lead have forced or driven the application of best available technology (BAT) for most of the potentially significant sources of cadmium emissions. If the ASARCO plant at El Paso is reopened then the SIP's for lead would require enclosures for dust handling processes significantly reducing cadmium emissions from this operation.

B. Primary Copper Smelters

As an impurity in copper ore concentrates, cadmium is emitted in varying quantities at each stage of the smelting process. The typical copper ore contains 0.01 percent cadmium. The distribution of cadmium

TABLE 1. INVENTORY OF EMISSIONS SOURCES AND CONTROLS FOR PRIMARY LEAD SMELTERS

Plant/Location	Source	Type[a]	Emissions kg/yr	Control[b]
Amax, Boss, MO	Main stack; blast furnace weak sinter	H	1,150.0	Baghouse
	Sinter/flast furn. fugitives	H	18.0	Baghouse
	Sinter prep/returns	H	40.0	Scrubber
	Sinter prep/returns	H	36.0	Scrubber
	Blast furnace charge prep	H	111.0	Scrubber
	Blast furnace charge prep	H	108.0	Scrubber
	Blast furnace charge prep	H	18.0	Scrubber
	Blast furnace charge prep	H	11.0	Scrubber
	Combined area fugitives	F	19.7	Enclosures, wet suppression
	Combined process fugitives	F	498.0	Enclosed conveyer, dust storage, BF air control, wet suppression
	TOTAL		2,010.0	
ASARCO, East Helena, MT	Sinter machine	H	240.0	Baghouse
	Zinc fume stack	H	75.0	Baghouse
	Blast/reverb furnaces	H	2,502.0	Baghouse
	Combined area fugitives	F	105.5	Wet suppression, sweeping
	Combined process fugitives	F	146.0	BF fugitive hoods, BF air control, dross charging covers and ventilation
	TOTAL		3,070.0	
ASARCO Glover, MO	Sinter machine (main stack)	H	598.0	Baghouse
	Blast furnace	H	247.0	Baghouse
	Sinter returns fugitives	H	3.5	Baghouse
	Mixing/pelletizing concs.	H	10.0	Scrubber
	Combined area fugitives	F	39.8	Wet suppression, sweeping
	Combined process fugitives	F	40.3	
	TOTAL		939.0	
St. Joe, Herculaneum, Mo.	Main stack: acid plant (AP) sinter machine blast furnace	H	8,470.0	Baghouse
	Sinter discharge	H	15.0	Scrubber
	Drums/conveyors	H	1.3	Scrubber
	Rolls/conveying	H	50.0	Scrubber
	Vib/conveyor belts	H	36.0	Scrubber
	Returns conveyor	H	0.2	Scrubber
	Sinter plant fugitives	H	3.0	Scrubber
	Combined area fugitives	F	7.9	Enclosure, wet suppression
	Combined process fugitives	F	82.8	
	TOTAL		8,660.0	
ASARCO, El Paso, TX	Sinter machine (lead stack)	H	300.0	Baghouse
	Blast furnace stacks	H	1,810.0	Baghouse
	Zinc fume baghouse stack	H	91.0	Baghouse
	Pb unloading stack	H	13.6	Baghouse
	Pb bedding bldg. stack	H	104.0	Baghouse
	Cadmium oxide production	H	2,720.0	Baghouse
	Combined area fugitives	F	3.3	Enclosure, wet suppression
	Combined process fugitives - dust handling	F	1,610.0	Wet suppression of dust
	TOTAL		6,660.0	

[a]H = point source; F = fugitive source.

[b]BF = blast furnace; AP = acid plant.

through the copper smelting process is shown in Figure 4. If the smelter uses a roaster, approximately 15 percent of the incoming cadmium will be volatilized in the roasting step. The remainder stays with the calcine and is charged to the smelting furnace. If there is no roaster, concentrates are charged directly to the smelting furnace. About one-third of the cadmium input to the smelting furnace is volatilized and two-thirds is retained in the matte. The matte passes from the smelting furnace to the converters where approximately 80 percent of the remaining cadmium is volatilized. The remaining 20 percent of the converter input is entrained in the converter slag which is returned to the smelting furnace or is discarded.

Since copper ore concentrates contain a significant amount of sulfur, most copper smelters also have acid plants to convert the SO_2-containing off-gas streams to sulfuric acid. Off-gases from the converters, and less often from the smelting furnace if a flash or electric smelting furnace is used, are pretreated for particulate matter removal and vented to an acid plant. At ASARCO-El Paso multiple hearth roasters are used with the off-gases treated at an acid plant. The acid plant tailgas is virtually free of particulate matter and cadmium. Pretreatment is usually accomplished by an ESP followed by wet treatment devices.

A review of the cadmium emission sources and their corresponding controls currently applied is presented in Table 2. Electrostatic precipitators are the control most often used on process off-gases for particulate control. Eleven smelters have an acid plant that employs additional wet treatment devices to reduce particulate from process off-gases from roasters and converters. The two plants that stand out as high emitters are Phelps Dodge-Douglas and Kennecott-McGill. Neither facility has acid plant control on the converter off-gases. In the case of Phelps Dodge-Douglas, the converter off-gas stream is vented directly to the atmosphere after ESP control, and for Kennecott-McGill the converter off-gas stream is vented to the atmosphere after multiclone control. These two plants are presently not operating. If the plants are restarted, then acid plants would have to be installed in order to meet SO_2 standards. The cadmium emissions from the two plants would then be sharply reduced.

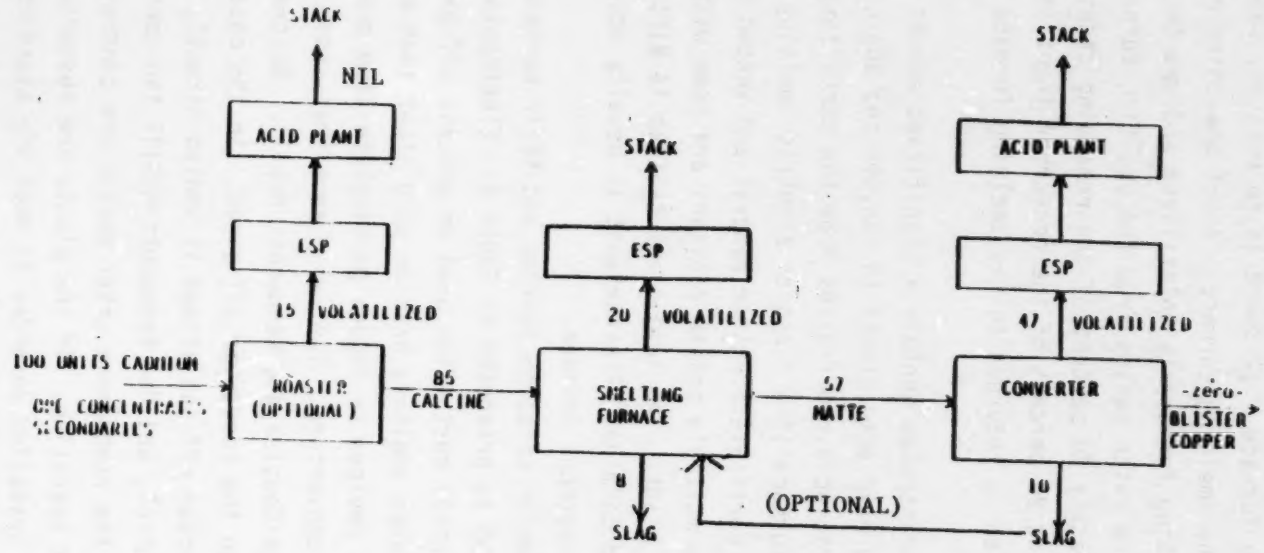

Figure 4. Cadmium distribution in the copper smelting process.

TABLE 2. INVENTORY OF EMISSIONS SOURCES AND CONTROLS FOR PRIMARY COPPER SMELTERS

Plant/Location	Source	Type	Emissions kg/yr	Control
ASARCO, El Paso, TX	Main stack (smelting furnace)	H	998.0	ESP
	Calcine slag matte tapping	F	53.0	Baghouse (matte), ESP (calcine)
	Combined area fugitives	F	54.2	--
	Converter fugitives	F	54.0	2*hoods, baghouse
	Cu unloading stack	H	204.0	Baghouse
	Cu transfer stack	H	10.2	Baghouse
	Cu bedding bldg. stack	H	104.0	Baghouse
	TOTAL		1,270.0	
ASARCO, Hayden, AZ	Main stack (all processes)	H	775.0	ESP, AP
	Matte and slag tapping	F	42.0	ESP
	Combined area fugitives	F	54.5	Wet suppression
	Converter fugitives	F	83.0	ESP
	TOTAL		954.0	
Cities Service Copperhill, TN	Matte and slag tapping	F	9.0	--
	Combined area fugitives	F	46.3	--
	Converter fugitives	F	14.0	--
	TOTAL		69.3	
Copper Range, White Pine, MI	Main stack (all processes)	H	102.4	Reverb: ESP. Converter: baloon flue
	Matte and slag tapping	F	16.0	--
	Combined area fugitives	F	3.1	--
	Converter fugitives	F	42.0	--
	TOTAL		164.0	
Inspiration Copper, Miami, AZ	Furnace/converter/AP stack	H	30.2	ESP, AP
	Matte and slag tapping	F	30.0	--
	Combined area fugitives	F	1.4	--
	Converter fugitives	F	84.0	--
	TOTAL		146.0	
Kennecott Copper, Garfield, UT	Main stack (all processes)	H	640.0	ESP, AP
	Matte and slag tapping	F	49.0	--
	Combined area fugitives	F	27.5	--
	Converter fugitives	F	137.0	--
	TOTAL		854.0	
Kennecott Copper, Hayden, AZ	Smelting furnace stack	H	57.0	ESP
	Roaster/converter/AP stack	H	25.5	Cyclone, scrubber, AP
	Calcine/matte/slag tapping	F	48.0	--
	Combined area fugitives	F	3.7	--
	Converter fugitives	F	77.0	--
	TOTAL		211.0	
Kennecott Copper, Hurley, NM	Main stack (all processes)	H	827.0	ESP, AP
	Matte/slag tapping	F	36.0	--
	Combined area fugitives	F	36.0	--
	Converter fugitives	F	98.0	
	TOTAL		997.0	
Kennecott Copper, McGill, NV	Main stack (all processes)	H	4,850.0	Reverb: ESP. Converter: cyclone
	Matte and slag tapping	F	33.0	--
	Combined area fugitives	F	0.1	--
	Converter fugitives	F	91.0	--
	TOTAL		4,980.0	

TABLE 2 (cont.). INVENTORY OF EMISSIONS SOURCES AND CONTROLS FOR PRIMARY COPPER SMELTERS

Plant/Location	Source	Type	Emissions kg/yr	Control
Magma Copper, San Manuel, AZ	Smelting furnace stack	H	378.0	ESP
	Converter/AP 1 stack	H	19.3	ESP, AP
	Converter/AP 2 stack	H	19.3	ESP, AP
	Matte and slag tapping	F	87.0	--
	Combined area fugitives	F	5.0	--
	Converter fugitives	F	240.0	--
	TOTAL		749.0	
Phelps Dodge, Ajo, AZ	Main stack (all processes)	H	1,990.0	ESP, AP
	Matte and slag tapping	F	12.0	--
	Combined area fugitives	F	0.2	--
	Converter fugitives	F	32.0	--
	TOTAL		2,030.0	
Phelps Dodge, Douglas, AZ	Main stack (roaster, smelting)	H	3,540.0	ESP
	Converter stack	H	12,000.0	ESP
	Calcine/matte/slag tapping	F	101.0	Baghouse (calcine only), ESP (other)
	Combined area fugitives	F	2.5	--
	Converter fugitives	F	160.0	--
	TOTAL		15,800.0	
Phelps Dodge, Hidalgo, NM	AP stack	H	1,640.0	ESP, AP
	Slag furnace stack	H	16.3	Scrubber
	Matte and slag tapping	F	54.0	--
	Combined area fugitives	F	31.1	--
	Converter fugitives	F	147.0	--
	TOTAL		1,880.0	
Phelps Dodge, Morenci, AZ	Converter/AP stack	H	42.0	ESP, AP
	Matte and slag tapping	F	31.0	--
	Combined area fugitives	F	36.7	--
	Converter fugitives	F	85.0	--
	TOTAL		195.0	

[a] H = point source; F = fugitive source.

Process fugitive emissions for each copper smelter also are presented in Table 2. The largest source of fugitive emissions is the converters. An emission factor for process fugitive cadmium emissions from converters was developed from a test performed in 1983.[11] Emission factors for matte and slag tapping fugitive emissions from reverberatory furnaces were taken from the previous source survey (GCA, 1981).[12] These factors indicate that process fugitive emissions are about three times greater from converters than from reverberatory furnaces--roughly the same proportion as the point source emissions discussed previously. Process fugitive emissions from roasters were considerably lower than fugitive emissions from the reverberatory furnace and the converter. Process fugitive emissions from roasters and smelting furnace tapping operations (matte and slag) are generally captured by local ventilation systems. Roaster emissions are typically controlled in a baghouse or ESP, while the furnace tapping emissions are typically discharged to the atmosphere uncontrolled. Six smelters have some degree of secondary or fugitive emissions capture. In only two cases, the ASARCO El Paso and Hayden smelters, are the capture systems considered to be effective and the captured emissions controlled. The El Paso smelter uses a baghouse for control and the Hayden smelter uses an ESP. Except for these plants no primary copper smelters employ process fugitive controls on roasters, smelting furnaces, or converters.

III. PUBLIC HEALTH RISKS

A. Approach

Risk assessment is the process used by EPA to develop quantitative estimates of public health risks associated with individual and population exposure to a hazardous or toxic air pollutant. The resultant estimates are considered by EPA to be rough but plausible upper-bound approximations of the risks. Two measures of risk are calculated. One is maximum individual risk and the other is aggregate risk. Maximum individual risk (MIR) is an estimate of the probability of contracting cancer experienced by the person or persons exposed to the highest predicted annual average concentration of the pollutant. Aggregate risk is an estimate of the increased number of cancer cases for the entire population exposed. It is expressed in terms of annual incidence or number of cancer cases per year.

The estimates are calculated by coupling a numerical constant that defines the statistical exposure-risk relationship for a particular hazardous pollutant with estimates of public exposure to the pollutant. The numerical constant used by EPA in its analysis of carcinogens is called a unit risk factor. It represents an estimate of the increase in lifetime cancer risk occurring to a hypothetical individual exposed continuously over a lifetime (70 years) to a concentration of 1 microgram per cubic meter (ug/m^3) of the pollutant in the air the individual breathes. For cadmium, the unit risk factor is estimated to be 1.8x10-3 or 1.8 chances in 1,000.[13]

Estimates of public exposure are derived using an atmospheric dispersion model and census data contained in EPA's Human Exposure Model (HEM).[14] Dispersion models are used to predict concentrations of a pollutant in the ambient air at varying distances and directions from a stationary emission source. By combining the predicted ambient concentrations with population distribution data, both the number of people exposed and their levels of exposure can be calculated. Needed inputs to the model include plant location (latitude and longitude) and source specific data including the height and area of the release point, temperature and velocity of exit gases, and emissions rate for each source to be modeled.[14] Details of the methods used to develop the health risk estimates for both source categories are described below.

1. Primary lead smelters. The inputs to the HEM, including emission estimates and stack parameters, for primary lead smelters were generated from Section 114 request responses, test reports, trip reports, State implementation plans (SIP's) for lead emissions, and the previous source survey (Radian, 1985). Although two smelters are currently closed, plans are for both smelters to reopen when the market for lead improves. Therefore, all five primary lead smelters were included in the risk assessment.

All stack sources at lead smelters were modeled individually. Fugitive emission estimates were modeled in separate groups. Process fugitive emissions were modeled in several different ways based on how the States had estimated the emissions. At ASARCO-East Helena and ASARCO-

Glover, process fugitive emissions tests had been conducted by MRI in 1977.[15] At these smelters, the buildings from which the process fugitives escaped (the sinter building, the blast furnace building, and the drossing building) were modeled as individual sources. For the other smelters the lead SIP estimates for lead process fugitives were multiplied by a cadmium-to-lead ratio and modeled as a group. Open fugitives were modeled as one source consisting of ore storage and slag pile emissions.

2. Primary copper smelters. The HEM inputs for primary copper smelters were generated from Section 114 request responses, EPA-sponsored and State-sponsored tests, trip reports, the Background Information Document for Arsenic emissions (Reference 4), and the previous cadmium source survey for primary copper smelters (GCA, 1981). All 14 copper smelters, whether operating, closed, or scheduled for closure, were included in the risk assessment. This was done because the modeling of all 14 smelters was manageable and because of uncertainties regarding whether closures and reopenings will actually occur.

The emissions from copper smelters were grouped by source types for the HEM modeling. All stacks were modeled as individual sources. In addition, each smelter was modeled with three types of fugitive emissions: area fugitive emissions, combined process fugitive emissions, and converter fugitive emissions. Area fugitives are comprised of emissions from ore storage and slag piles. Combined process fugitives include emissions from matte and slag tapping of the smelting furnace, and, if roasters are used, calcine transfer emissions. Converter fugitive emissions, the major fugitive source, were modeled separately.

B. Results

1. Primary lead smelters. Table 3 shows the emissions, maximum individual risk, and annual incidence for each plant. Three smelters had maximum individual risk exceeding or approaching 1×10^{-4}: ASARCO-El Paso, ASARCO-East Helena, and AMAX-Boss. ASARCO-El Paso clearly has the highest maximum individual risk (2.03×10^{-3}), and El Paso's annual incidence of 0.056 is 78 percent of the total incidence for the source category. Table 3 also shows that the HEM model predicts that there is less than one person located at the point of maximum risk meaning, in general, that the

TABLE 3. SUMMARY OF EMISSIONS AND RISKS FOR PRIMARY LEAD SMELTERS

Plant/Location	Operating Status	Cadmium Emissions, kg/yr	Maximum Individual Risk	Incidence case/yr	People exposed to: Maximum concentration	People exposed to: Total
ASARCO, El Paso, TX	Closed	6,820	2.00×10^{-3}	0.056	<1	493,000
ASARCO, East Helena, MT	Open	3,070	1.30×10^{-4}[a]	0.0005	<1	48,600
ASARCO, Glover, MO	Open	940	7.16×10^{-7}	0.0002	123	97,300
AMAX, Boss, MO	Closed	2,010	9.58×10^{-5}[a]	0.0004	<1	52,800
St. Joe, Herculaneum, MO	Open	8,660	3.47×10^{-5}	0.015	3	1,500,000
		21,500		0.072		

[a] Review of USGS maps indicates it is unlikely that anyone resides at location of maximum risk predicted by HEM. More plausible MIR estimates are 5.97×10^{-5} for ASARCO-East Helena and 4.5×10^{-5} for AMAX-Boss.

population immediately surrounding the smelter is sparse.[a] Subsequently, USGS topographic maps were analyzed to determine the location of the point of maximum concentration predicted by the HEM. The maximum concentration and point of maximum risk was predicted to be 200 meters from the center of each smelter. For the ASARCO-East Helena smelter, this point appeared to be on plant property. A more plausible point of maximum risk lies at 500 meters from the center of the plant. Using this point, a more plausible value for maximum individual risk is 5.96×10^{-5}. The AMAX-Boss smelter is located in a national forest. The more plausible point of maximum risk is 1,000 meters from the smelter. The more plausible maximum individual risk that corresponds to this point is 4.5x10-5. For the ASARCO-El Paso smelter it was concluded that people could reside at the point of maximum concentration.

2. Primary copper smelters. Table 4 shows the emission rate and public health risks for each smelter. All smelters have less than 1x10-4 MIR and incidence below 0.01 case per year. The total annual incidence for the source category is 0.008 case. The highest risks and incidences in the copper category were for fugitive emissions from copper converters and smelting furnaces. However, these sources had lower risks than most of the sources in the lead category. The converter fugitives with the highest MIR all had risks considerably lower than 1x10-4. The highest risk for any one source (3.9x10-5) was for converter fugitives at Magma Copper, San Manuel, Arizona.

IV. POTENTIAL FOR IMPROVED CONTROL

A. Primary Lead Smelters

The potential for improved control was evaluated at the sources that drive the health risks at the three high-risk primary lead smelters

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[a]The HEM model uses population data from the 1980 census. Population is divided into block enumeration groups which are defined roughly by the number of people a census taker can cover in 1 day. Each enumeration group is assigned a location. If an enumeration group is within 3.5 km of the source, the enumeration group's population is apportioned among 96 receptor sites at which the HEM model predicts pollutant concentration. If there is only one block enumeration group within 3.5 km and its population is less than 96 persons, fewer than one person is assigned to each receptor site.

TABLE 4. SUMMARY OF EMISSIONS AND RISKS FOR PRIMARY COPPER SMELTERS

Plant/Location	Operating Status	Cadmium Emissions, kg/yr	Maximum Individual Risk	Incidence case/yr	People exposed to: Maximum concentration	People exposed to: Total
ASARCO, El Paso, TX	Open	1,270	3.90×10^{-5}	0.0042	<1	493,000
ASARCO, Hayden, AZ	Open	950	5.35×10^{-5}	0.0001	1	46,800
Cities Service, Copperhill, TN	Closed	70	3.56×10^{-5}	0.0001	<1	164,000
Inspiration Copper, Miami, AZ	Open	150	2.14×10^{-5}	0.0001	<1	35,700
Kennecott Copper, Garfield, UT	Closed	850	2.50×10^{-7}	0.0005	2	810,000
ASARCO (Ray Smelter) Hayden, AZ	Closed	210	3.93×10^{-5}	0.0001	1	46,800
Kennecott Copper, Hurley, NM	Open	1,000	5.42×10^{-5}	0.0001	<1	26,300
Kennecott Copper, McGill, AZ	Closed	4,980	4.61×10^{-5}	<0.0001	<1	7,350
Copper Range, White Pine, MI	Open	160	9.43×10^{-6}	<0.0001	<1	16,900
Magma Copper, San Manuel, AZ	Open	750	5.84×10^{-5}	0.0002	<1	211,000
Phelps Dodge, Douglas, AZ	Closed	15,790	5.41×10^{-5}	0.0017	1	31,100
Phelps Dodge, Ajo, AZ	Closed	2,030	1.37×10^{-5}	0.0003	114	6,600
Phelps Dodge, Hidalgo, NM	Open	1,880	6.37×10^{-6}	0.0001	909	2,560
Phelps Dodge, Morenci, AZ	Closed	190	4.60×10^{-5}	0.0003	2	25,500
		30,300		0.0079		

described previously. These high risk sources are shown in Table 5. Three sources at ASARCO-El Paso are responsible for more than 95 percent of the incidence at this smelter: the cadmium oxide product collection baghouse, combined process fugitives (70 percent of which is due to blast furnace baghouse dust handling), and the blast furnace baghouse stacks.

Cadmium oxide, produced from roasting cadmium-bearing blast furnace baghouse dust, is blown to a product collection baghouse. Emissions from the baghouse are vented to a large louvered cupola. Although the outlet particulate matter concentration is low, 0.0125 gr/dscf, 66 percent of the particulate matter is cadmium. Furthermore, the emissions are very poorly dispersed due to the low stack velocity (0.1 m/s) and stack height (14 m). The poor dispersion, plus the high emission rate of 2,720 kg/yr, combine to boost the MIR for this source.

Another high risk source at the El Paso smelter is process fugitive emissions. Seventy percent of the process fugitive emissions rate is due to the blast furnace baghouse dust handling. The TACB has estimated the lead emissions from this source for the SIP. The cadmium emissions were estimated to be 1,610 kg/yr using a cadmium-to-lead ratio supplied by ASARCO. The MIR from fugitive emissions is 3.54x10-4, and the annual incidence is 0.014 case/yr. However, if this plant is reopened then the lead SIP would require that these process fugitives be controlled. The blast furnace baghouse at El Paso has six separate cellars where dust catches are stored. To remove this dust, which is up to 18 percent cadmium, plant personnel open the cellar doors and transfer the dust by bucket loader to a railcar for transport to the cadmium plant. Water is sprayed on the bucket loader's path and on the dust in the railcar during dumping to minimize fugitive emissions.

The third significant source at the El Paso smelter is the blast furnace. These emissions are controlled by a large baghouse and are vented through six stacks. Test reports have shown that the outlet grain loading is 0.0046 gr/dscf of particulate matter and 0.00039 gr/dscf of cadmium.[16]

At ASARCO-East Helena and AMAX-Boss the process fugitive emissions controlled the majority of the risk although both of these sources had MIR's less than $1x10^{-4}$. At ASARCO-East Helena the process fugitives were primarily from the blast furnace and dross furnace. Controls for this

TABLE 5. SUMMARY OF HIGH RISK SOURCES AT LEAD SMELTERS

Plant/Location	Source	Cadmium emissions, kg/yr	People	Maximum risk	Annual incidence, case/yr
ASARCO, El Paso, Tex.	CdO baghouse	2,722	493,000	1.57×10^{-3}	0.025
	Process fugitives	1,613	493,000	3.54×10^{-4}	0.014
	Blast furnace stacks	1,814	493,000	9.71×10^{-5}	0.012
ASARCO, East Helena, Mont.	Process fugitives	146	48,600	1.11×10^{-4}[a]	0.0001
AMAX, Boss, Mo.	Process fugitives	498	52,800	8.26×10^{-5}[a]	0.0004

[a]Review of USGS maps indicates it is unlikely that anyone resides at the location of maximum risk predicted by the HEM. More plausible MIR estimates are 4.06×10^{-5} for ASARCO-East Helena and 3.90×10^{-5} for AMAX-Boss.

source have been installed as a result of the requirements of the Montana lead SIP. These controls include: blast furnace air controls, blast furnace secondary hooding vented to a baghouse, covers for the dross kettles, and improved ventilation for the dross kettles. At AMAX-Boss the primary emission source was baghouse dust handling. The controls present for this source include a covered conveyor for transfer of recycled dusts, an enclosed dust storage building, and pug mill wetting of baghouse dusts prior to storage.

All high risk sources in Table 5 were investigated for possible improvements in control. For three of the five sources best available control is considered to be in place. The blast furnace emissions at ASARCO-El Paso are controlled by a baghouse, and the outlet grain loading have been tested to be 0.0046 gr/dscf total particulate.[13] Further emission reductions are not likely.

For ASARCO-East Helena, a number of control devices have been required by the lead SIP to control process fugitive emissions from the blast furnace and dross furnace (see Section III.B). These controls are considered to be best available technology. Process fugitive control at AMAX-Boss also is considered to be best available technology. To control process fugitives from dust handling, AMAX has enclosed storage buildings and installed a covered conveyor for dust transfer.

For the two remaining high-risk sources, the cadmium oxide baghouse and process fugitives from dust handling at ASARCO-El Paso, improved controls are technically feasible. Table 6 shows the possible control improvements for these high-risk sources at ASARCO-El Paso along with the associated costs and cost effectiveness.

For the cadmium oxide baghouse at ASARCO-El Paso, the emissions have been estimated by mass balance to be approximately 2.7 Mg/yr. This estimate corresponds to an outlet grain loading of 0.012 gr/dscf.[b] Baghouse experts consulted believe that 0.005 gr/dscf may be achievable,

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[b]This grain loading is based on the emissions estimate of 2,722 kg/yr of cadmium and the gas flow rate. Both were provided on ASARCO's Section 114 information request response. The stack has a 5.5 meter equivalent diameter with an exit velocity of approximately 0.1 m/s. The configuration and placement of this stack preclude emission testing for this source. The emission estimate is based on a TACB mass balance or the cadmium plant.

TABLE 6. COSTS OF IMPROVED CONTROL FOR HIGH-RISK SOURCES AT LEAD SMELTERS

Plant/Location	Source	Source category	Improved control	Emission reduction, Mg/yr	Maximum risk after control	Annual incidence (reduction)	Costs, $		Cost effectiveness,	
							Capital	Annual	$/Mg	$/life
ASARCO, El Paso, Tex.	C40 baghouse	Pb	Switch to better bag	1.633	6.28×10^{-4}	0.01 (0.015)	31,900	6,700	4,100	446,000
	Process fugitives (dust handling)	Pb	Enclose transfer points	1.210	8.85×10^{-5}	0.001 (0.013)	None[a]	None[a]	Mandated by Texas for lead SIP. Will put in place before plant reopens.	
	Blast furnace baghouse stacks	Pb	Best Available Technology (BAT) in place							
ASARCO, East Helena, Mont.	Process fugitives	Pb	BAT in place							
AMAX, Boss, Mo.	Process fugitives	Pb	BAT in place							

[a]Mandated by TACB for lead SIP. Improved control will be in place before lead . ter reopens. Thus, costs cannot be charged to cadmium control.

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and, based on the limited data available, one possible means for reducing the emissions is changing the type of bag material used.[c] One bag manufacturer would guarantee to meet 0.005 gr/dscf or less.17 The capital cost in Table 6 reflects the cost to purchase and install 135 felt-type or Goretex-type bags. The annualized cost reflects the incremental cost difference between use of the current bags and use of the new, more expensive bags. The cost/benefit ratio for this source is far lower than the cost of other options, such as installing a new control system. Goretex-type bags. The annualized cost reflects the incremental cost difference between use of the current bags and use of the new, more expensive bags. The cost/benefit ratio for this source is far lower than the cost of other options, such as installing a new control system. However, this cost/benefit ratio is an uncertain figure because of the uncertainty of the emission estimate and because the diagnosis of the problem is based on limited information. Further onsite investigation is needed before the true emission reduction can be assessed.

The second high-risk source at El Paso, process fugitives from blast furnace baghouse dust handling, can also be controlled. The State of Texas has mandated control for this source in the SIP for lead emission reductions. The future handling of any dust containing greater than 1 percent lead must be done in an enclosed space ventilated to a fabric filter. Should ASARCO decide to reopen the lead smelter, they plan to construct an enclosure for blast furnace dust handling. Thus, although control is not now in place, it will be installed before the lead smelter reopens. Based on a 75 percent control efficiency, the MIR after control will fall from 3.54×10^{-4} to 8.85×10^{-5}.

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[c]The baghouse seems to be well operated and maintained with an air-to-cloth (A/C) ratio of 1.04:1. Since the A/C ratio is already low, reducing this ratio would not significantly reduce emissions. Therefore, additional filtering area or a new baghouse are not plausible solutions. Further, the mean particle diameter for cadmium oxide is approximately 1 micrometer. With a small particle size such as this, particle bleed-through is a potential problem particularly with the woven bag currently in use. A plausible solution is changing to a felt-type or Goretex -type coated bag.

B. Primary Copper Smelters

A summary of the highest converter and reverberatory furnace risks are presented in Table 7. The sources in this table represent the sources of highest risk within the category, but MIR's for all sources are less than $1x10^{-4}$. In addition, these data show that cancer incidence is extremely low for the copper source category.

The other emission source that was investigated further was the converter stack at Phelps Dodge in Douglas, Arizona. This source had the highest cadmium emission rate in either source category, 12 Mg/yr. However, because of the extensive dispersion and the low population density, the incidence and MIR are relatively low, 0.0011 case/yr and $6.5x10^{-4}$, respectively. Converter process emissions result from the off-gases of the molten matte undergoing conversion; the off-gas stream is drawn through an ESP. Most copper smelters vent these emissions to an acid plant for further treatment. The Douglas smelter vents it to the atmosphere because they do not have an acid plant. This not only results in high cadmium and particulate matter emissions, but also a high SO_2 emission rate. The Douglas plant is scheduled for closure in January 1987 by agreement between Phelps Dodge and EPA because of the high SO_2 levels in the area.

Improved control is technically feasible for copper smelters; fugitive arsenic emissions from converters and reverberatory furnaces have been identified and evaluated, and control costs are presented in the Arsenic BID.[4] Table 8 summarizes the costs of the improved control.

Improved control for converters, consisting of air curtain secondary hoods vented to a baghouse, was evaluated to have a 90 percent capture efficiency.[4] Likewise, conventional hoods vented to a baghouse were rated at 90 percent capture efficiency for controlling the reverberatory fugitives.4 Thus, use of these controls could reduce cadmium emissions and risk approximately ten-fold. However, if these controls were implemented, the costs (as shown in Table 8) would be high. The copper converters and reverberatory furnaces for which improved control was assessed were chosen because they had the highest risks and incidences in the copper category and because it was possible to use the technical data and costs in the

TABLE 7. SUMMARY OF HIGH RISK SOURCES AT COPPER SMELTERS

Plant/Location	Source	Cadmium Emissions kg/yr	People	Maximum Risk	Annual Incidence case/yr
Magma, San Manuel, AZ	Converter fugitives	240	211,000	3.90×10^{-5}	0.00013
Phelps Dodge, Douglas, AZ	Converter fugitives	160	31,000	2.31×10^{-5}	0.00018
	Matte/slag tapping	3,500	31,000	3.07×10^{-5}	0.00016
	Converter stack	12,000	31,000	6.59×10^{-6}	0.00111
ASARCO, Hayden, AZ	Converter fugitives	83	46,800	1.40×10^{-5}	0.00004
Kennecott, Garfield, UT	Converter fugitives	137	810,000	1.31×10^{-7}	0.00022
ASARCO, El Paso, TX	Matte/slag tapping	53	493,000	1.04×10^{-5}	0.00045

TABLE 8. COSTS OF IMPROVED CONTROL FOR HIGH-RISK SOURCES AT COPPER SMELTERS

Plant/Location	Source	Source Category	Improved Control	Emission Reduction Mg/yr	Maximum Risk After Control	Annual Incidence (reduction)	Costs		Cost Effectiveness	
							Capital	Annual	$/Mg	$/Life
Magma Copper, San Manuel, AZ	Converter fugitives	Cu	Air curtain secondary hoods vented to baghouse	0.216	3.9×10^{-6}	0.00001 (0.00012)	1.3×10^{7}	4.0×10^{6}	1.35×10^{7}	3.45×10^{10}
Kennecott, Garfield, UT	Converter fugitives	Cu	Air curtain secondary hoods vented to baghouse	0.123	1.31×10^{-8}	0.00002 (0.0002)	5.2×10^{6}	1.3×10^{6}	1.1×10^{7}	6.6×10^{9}
Phelps Dodge, Douglas, AZ	Converter fugitives	Cu	Air curtain secondary hoods vented to baghouse	0.144	2.31×10^{-6}	0.00002 (0.00016)	9.8×10^{6}	2.8×10^{6}	1.97×10^{7}	1.71×10^{10}
	Reverb furnace	Cu	Hooding for matte and slag tapping	0.091	3.07×10^{-6}	0.00002 (0.00014)	1.8×10^{6}	5.1×10^{5}	5.6×10^{6}	3.5×10^{9}
	Converter stack	Cu	99 percent efficient ESP (baseline is 94.8 percent)	9.68	1.26×10^{-6}	0.00021 (0.0009)	7.5×10^{6}	6.0×10^{5}	6.23×10^{4}	6.7×10^{8}

Arsenic BID to evaluate the cost effectiveness for reducing cadmium emissions. Also, by choosing the sources of highest risk for the cost-effectiveness evaluation, the most optimistic estimates for cost effectiveness were obtained because risk and incidence reductions were maximized.

The one process point source for which improved control costs were calculated was the converter stack at Phelps Dodge-Douglas. The current ESP control is 94.8 percent efficient as calculated from the emission estimate. Improved control evaluated for this source is a 99-percent efficient ESP. The major benefit derived from additional control is a reduction in the incidence from 0.001 case/yr to 0.0002 case/yr. The MIR would also be reduced.

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